

ENERGY CONVERSION SYSTEMS USING NANOMETER SCALE  
ASSEMBLIES AND METHODS FOR USING SAME

Background of the Invention

[0001] This invention relates to nanometer scale  
5 electromechanical systems. In particular, the present  
invention relates to nanometer scale electromechanical  
systems that may be used in various applications, such  
as heat engines, heat pumps, or propulsion systems.

[0002] Electromechanical systems that rely on  
10 molecular motion are known. For example, U.S. Patent  
No. 4,152,537 (the "'537 patent"), describes an  
electricity generator that produces electrical energy  
from the random movement of molecules in a gas, and the  
uneven distribution of thermal energy in different  
15 molecules of the gas, which is at an overall uniform  
temperature.

[0003] Other such systems are described in, for  
example, U.S. Patent Nos. 3,365,653; 3,495,101,  
2,979,551; 3,609,593; 3,252,013 and 3,508,089. These  
20 systems produce electricity or devices driven by  
electricity, such as an oscillator, based on molecular  
motion and thermal energy.

[0004] One problem common to all of these systems is  
the low level of output power when compared to the  
25 amount of power required to operate the systems. For  
example, such systems often require a certain amount of

energy to maintain the systems at a constant overall temperature. While the '537 patent attempted to address some of the known deficiencies in such systems, the electricity generator described therein also  
5 suffers from similar deficiencies. For example, the '537 patent attempts to heat the thermocouple junction between two dissimilar materials by simply being in contact with a gas-molecule having an above-average speed. In addition, the '537 patent utilizes an  
10 array of electrical rectifiers (see, e.g., rectifier bridge 40 in FIGS. 2 and 4) that may have difficulty in operating properly due to the infinitesimally small voltages produced at the molecular scale.

[0005] Moreover, as the use of electronic devices  
15 continues to flourish, there is an ever increasing need to provide more efficient and/or quieter ways to cool the components that are typically the heart of such devices. For example, most personal computers include one or more fans that are required to maintain the  
20 temperature of the microprocessor within a certain operational range. These fans are often noisy, and often result in large quantities of dirty air being pulled through the computer from the air intakes.

[0006] Accordingly, it is an object of the present  
25 invention to provide nanometer scale electromechanical systems that efficiently convert molecular-level energy into another form that can be used at a macroscopic scale.

[0007] Another object of the present invention  
30 is to provide nanometer scale electromechanical systems that efficiently convert molecular-level heat energy into useful mechanical and/or electrical energy.

[0008]

[0009] A still further object of the present invention is to provide nanometer scale electromechanical systems that utilize molecular-level energy to create a pressure differential on a surface  
5 of an object to propel the object in a controllable direction.

[0010] An even further object of the present invention is to provide nanometer scale electromechanical systems that utilize molecular-level  
10 energy to heat or cool an external substance.

#### Summary of the Invention

[0011] The nanometer scale electromechanical systems of the present invention efficiently convert molecular-level energy from one form into another form by  
15 reducing the velocity of the molecules within the working substance. These systems may include, for example, a heat engine that converts molecular-level heat energy into useful mechanical or electrical energy. Such systems may also include a heat pump that  
20 utilizes molecular-level energy to either heat or cool a substance. For example, a system of the present invention may be mounted to a microprocessor as the primary cooling device, so that little or no fans would be necessary. In addition, these systems may also  
25 include propulsion systems in which molecular-level energy is utilized to create a pressure differential on the surface of an object, thereby providing the ability to propel that object in a controllable direction.

[0012] Nanometer scale electromechanical systems  
30 constructed in accordance with the present invention may include a large number of nanometer-sized objects, such as paddles, impact masses, and/or tubes, that are

placed in a liquid or gas. These objects may be sized on the order of several nanometers per side, and may have a thickness on the order of about one or two nanometers. One side of the paddle is connected to a  
5 flexible, spring-like, attachment, that couples the paddles to a common base. Also attached to each paddle is some form of generator device, such as a piezoelectric, electromotive force or electrostatic generator, that converts random molecular motion into  
10 electrical, electromagnetic or thermal energy.

[0013] The nanometer-sized paddles, in conjunction with an associated generator, reduce the speed of individual molecules which results in a reduction of thermal energy within the working fluid. The generated  
15 electrical energy may be converted back to thermal energy at a higher temperature than the working fluid and used to establish a temperature differential that is capable of performing useful work. Essentially, the paddles are configured to be immersed in a working  
20 substance. The paddles move in a random manner within the working substance due to variations in the thermal motion of the molecules of the working substance. This movement necessarily results from collisions between the molecules of the working substance and the paddles  
25 which are large enough to cause the paddles to oscillate. The kinetic energy from this oscillation may then be converted into electrical, electromagnetic or thermal energy by various methods, as described above.

30 [0014] Nanometer scale electromechanical systems constructed in accordance with the present invention also provide components that efficiently collect and sum the outputs of the numerous paddles so that a useful electrical output is produced. For example, one

embodiment of the present invention includes the use of an array of resistive elements, one for each paddle, that are in contact with one side of the thermocouple. The other side of the thermocouple is placed in thermal  
5 contact with something else that is at an ambient temperature (such as a gas or liquid). Each of the thermocouples produces an output (i.e., a DC current and voltage) that can be summed through a simple series connection to produce an output, depending on the  
10 number of paddles and configuration, on the order of several milliwatts.

[0015] In one particular embodiment, a nanometer scale electromechanical system constructed in accordance with the present invention may include an  
15 array of nanotubes, such as tubes made of carbon, which are coupled between two plates of a capacitor. One of the tubes is physically connected to one plate of the capacitor, while the other end is free to move. The entire assembly is immersed in a fluid (i.e., a liquid  
20 or a gas). A voltage is applied to the capacitor (across the plates), which creates an electric field ("E") that keeps the length of the tubes perpendicular to the surface of the capacitor plate. The "free" ends of the tubes, which are immersed in a working  
25 substance, move erratically due to collisions between the molecules of the working substance and the tubes, causing some of the tubes collide into each other. Kinetic energy of the colliding tubes, as well as other energy, may be converted for one or more useful  
30 purposes, as previously described.

[0016] In another embodiment of the present invention, numerous nanotubes are connected at each end to an electrically and thermally conductive rail. Each of the tubes is installed such that there is slack, or

bend, in the tube. The slack permits the tubes to vibrate in response to random pressure variations from surrounding fluid (gas or liquid). In this case, an external magnetic field (" $\vec{B}$ ") is applied to the entire  
5 assembly which is perpendicular to the tubes and rails. Heat generated in the tubes, from the induced current, flows down the tubes to the thermally conductive rails, which are attached to a thermally conductive plate.  
[0017] Further features of the invention, its nature  
10 and various advantages will be more apparent from the accompanying drawings and the following detailed description of the preferred embodiments.

#### Brief Description of the Drawings

[0018] The above and other objects and advantages of  
15 the present invention will be apparent upon consideration of the following detailed description, taken in conjunction with accompanying drawings, in which like reference characters refer to like parts throughout, and in which:

20 [0019] FIG. 1A is an illustrative schematic diagram of a portion of a nanometer scale electromechanical system constructed in accordance with the present invention;

[0020] FIG. 1B is an illustrative schematic diagram  
25 of one embodiment of conversion circuitry constructed in accordance with the principles of the present invention;

[0021] FIG. 2 is an illustrative schematic diagram  
30 of a portion of another nanometer scale electromechanical system constructed in accordance with the principles of the present invention;

[0022] FIG. 3 is a perspective view of a portion of a nanometer scale electromechanical system constructed in accordance with the principles of the present invention;

5 [0023] FIG. 4 is a perspective view of a portion of another nanometer scale electromechanical system constructed in accordance with the principles of the present invention;

[0024] FIG. 5 is an illustrative schematic diagram  
10 of a nanometer scale electromechanical system constructed in accordance with the principles of the present invention;

[0025] FIG. 6 is an illustrative schematic diagram  
of another nanometer scale electromechanical system  
15 constructed in accordance with the principles of the present invention;

[0026] FIG. 7 is a perspective view of another  
nanometer scale electromechanical system constructed in  
accordance with the principles of the present  
20 invention;

[0027] FIG. 8 is an illustrative schematic diagram  
of a portion of the nanometer scale electromechanical  
system of FIG. 7;

[0028] FIG. 9 is another illustrative schematic  
25 diagram of a portion of the nanometer scale  
electromechanical system of FIG. 7;

[0029] FIG. 10 is a cross-sectional view of another  
nanometer scale electromechanical system constructed in  
accordance with the principles of the present  
30 invention;

[0030] FIG. 11 is a perspective, partial cross-  
sectional view of another nanometer scale

electromechanical system constructed in accordance with the principles of the present invention;

[0031] FIG. 12 is an illustrative schematic diagram of a portion of the nanometer scale electromechanical  
5 system of FIG. 11;

[0032] FIG. 13 is a perspective, partial cross-sectional view of another nanometer scale electromechanical system constructed in accordance with the principles of the present invention;

10 [0033] FIG. 14 is an illustrative schematic diagram of a portion of the nanometer scale electromechanical system of FIG. 13;

[0034] FIG. 15 is a cross-sectional plan view of the nanometer scale electromechanical system of FIG. 13  
15 taken along line 14-14;

[0035] FIG. 16 is an illustrative schematic diagram of a portion of the nanometer scale electromechanical system of FIG. 13; and

[0036] FIG. 17 is an illustrative schematic diagram  
20 of an electromechanical propulsion system constructed in accordance with the principles of the present invention.

#### Detailed Description of the Invention

[0037] FIG. 1A shows an illustrative example of a  
25 portion of a nanometer scale electromechanical system constructed in accordance with the present invention. The portion shown includes an impact mass in the form of paddle 100, a restraining member 102, an generator device 104 (which provides an electrical output at  
30 leads 106), and a base 108 (which is typically thousands or millions times larger than paddle 100). Paddle 100 is attached to base 108, which may be



thermally conductive, but need not be, so that paddle 100 may be moved within a predetermined range of distance in one or more directions (such as laterally, or up and down). A complete energy conversion system  
5 using nanometer scale assemblies would typically include a million or more of the devices shown in FIG. 1A, as will become more apparent below (see, for example, FIGS. 5 and 6).

[0038] Paddle 100 may be constructed, for example,  
10 from a substance such as carbon or silicon, although persons skilled in the art will appreciate that variations may be made in the fabrication materials of paddle 100 without departing from the spirit of the present invention. Moreover, paddle 100 can generally  
15 be manufactured using known semiconductor fabrication techniques such as sputtering, etching, photolithography, etc.

[0039] In addition, each paddle 100 may be constructed to be about five nanometers on each side,  
20 and have a height of about one to two nanometers -- this size being selected so that the effects of Brownian motion are large enough to overcome inertia of paddle 100 and the spring constant of restraining member 102. Persons skilled in the art  
25 will appreciate that the specific size of paddle 100 is not critical to the basic operation of the present invention, provided that paddle 100 is able to move in an irregular manner within the working substance as a result of random variations in the velocity of the  
30 working substance molecules that strike paddle 100.

[0040] Also shown in FIG. 1A, is molecule 110 which is shown as having bounced off of paddle 100, and is now traveling at a reduced velocity. Persons skilled

- in the art will appreciate that, while some molecules will have a reduced velocity as a result of the impact, others may exhibit little change in velocity, and others may actually achieve an increased velocity. In general however, and in accordance with the present invention, the impact of molecule 110 with paddle 100 results, on the average, with a reduction in velocity.
- [0041] The molecule is a molecule of the working substance of the system, which is preferably a fluid (i.e., a gas or a liquid), but may also be a solid. The fluid may be kept at atmospheric pressure or it may be kept at an elevated pressure, such as, for example a pressure in excess of about 15 PSI. As described above, the pressure of the working fluid may have an impact in the output provided by the system. Molecule 110 strikes paddle 100, thereby causing molecule 110 to experience a reduction in velocity. The reduction in velocity corresponds to a reduction in temperature of the working substance of the system.
- [0042] The reduction in velocity of molecule 110 is caused by paddle 100 in conjunction with device 104, which may be any one of a variety of devices without departing from the present invention. For example, device 104 may be a piezoelectric device, or it may be an electromotive force or electrostatic generator. In each instance, device 104 converts the energy of the impact mass, from the impact of molecule 110 into impact mass 100, into electrical energy that is output via leads 106.
- [0043] The amount of electrical energy output via leads 106, even under the most favorable conditions will be very small. For example, the output of paddle 100 may be on the order of about  $10^{-12}$  watts,

depending on the size of the device and various other factors. Accordingly, for the system to provide useful output power, such as, for example, a few microwatts, the system requires that millions of such paddles be  
5 fabricated, and that they be connected together in some fashion, so that the outputs of all, or substantially all, of them can be summed into a single output signal.

[0044] If a million or so of paddles 100 were arranged together in an array (see, for example,  
10 FIGS. 5 and 6), one way to sum all of the energy from each of those paddles would be to couple the leads 106 of each paddle 100 to resistive element 112 (see FIG. 1B), and have resistive element 112 be in thermal contact with one side 114 of thermocouple 116. The  
15 other side 118 of thermocouple 116 would then be in thermal contact with a heat sink or some other substance at ambient temperature (which may even include the working substance itself). Thermocouple 116 is a thermoelectric generator that,  
20 in response to a temperature differential, produces a voltage across a pair of leads and, if the leads are connected to a load, a DC current.

[0045] Variations in molecular impacts on paddle 100 will cause an increase in the temperature of resistive  
25 element 112, which will then be converted into electrical energy by thermocouple 116 and output via leads 120. One advantage of the use of resistive elements is the fact that, because a resistive load is independent of current/polarity direction, there is no  
30 need for a rectifier associated with each paddle. Thus, in accordance with the present invention, even infinitesimal voltages produced by the impacts of molecules 110 on paddles 100 can be used to heat resistive elements to useful values. Each thermocouple

in the array, in turn, produces an output having a DC voltage, and current if connected through an electrical load. All of these outputs can then be connected together in series to produce an output of at least  
5 several microwatts.

[0046] If additional power is needed, numerous subassemblies of paddles could be coupled together in series. For example, if a given subassembly was formed to include an array of paddle assemblies in which each  
10 assembly occupied approximately one hundred square nanometers, a square centimeter assembly would include roughly one trillion paddle assemblies. Then, any number of the one square centimeter subassemblies could be coupled together in series or parallel to achieve  
15 the desired ratio of voltage and current.

[0047] In addition, with a combined output on the order of approximately 700 mV, the output of each one square centimeter assembly could even be manipulated using conventional semiconductor switches. Thus, a  
20 given component could be fabricated by fabricating many one square centimeter assemblies next to each other on a thin, flexible sheet of material (such as aluminum) in a continuous process. The resultant sheets of material could then be cut up and rolled into a tube,  
25 similar to the fabrication process of some capacitors.

[0048] Persons skilled in the art will appreciate that the electrical output of these devices per unit surface area is proportional to the pressure of the fluid, the average temperature of the fluid, the  
30 oscillation frequency of the paddle and the mass of the fluid molecules used (regardless of whether the fluid is a gas or a liquid). The output per unit area is inversely proportional to the size of the paddle and

the density of the paddle material. Accordingly, by choosing a heavy molecule gas, such as xenon, or by using a fluid heavily laden with particulates, such as air laden with carbon molecules, and/or by immersing  
5 the paddles in the gas at elevated pressure, such as 100 times atmospheric pressure, the power output of the units can be increased by a factor of over 100, as compared with units operating in air at atmospheric pressure.

10 [0049] FIG. 2 shows a alternate embodiment of the paddle assembly shown in FIG. 1. In particular, the assembly in FIG. 2 varies from that in FIG. 1 in that restraining member 102 is coupled to a housing 208 instead of base 108. Housing 208 is a thermally  
15 conductive chamber which includes the ability to receive thermal inputs (shown as "Q" in FIG. 2). In this embodiment, the influx of heat Q is converted into electrical energy that is output via each of leads 106. In addition, while the assembly shown in FIG. 1 does  
20 not include a housing, it may be desirable, but is certainly not required, to locate that assembly in a housing as well, if only to protect it from contaminates.

[0050] The embodiment shown in FIG. 2 may be used  
25 to illustrate one of the advantages of the present invention, in that the nanometer scale energy conversion systems of the present invention may be used as a heat pump. For example, thermally conductive housing 208 will be cooled as a result of the molecular  
30 impacts on paddles 100 and subsequent conversion of the paddle kinetic energy into electrical energy. Warm or hot air may be cooled by blowing it across housing 208. On the other hand, resistive load 112 may be connected in series with leads 106, which results in the

temperature of resistive load 112 being raised.  
Cool air may be warmed by blowing it over resistive  
load 112. In this manner, the same assembly may be  
used to heat an external substance or to cool an  
5 external substance.

[0051] FIG. 3 shows another embodiment of a portion  
of a nanometer scale electromechanical system 300  
constructed in accordance with the principles of the  
present invention. The portion of system 300 shown  
10 in FIG. 3 includes three paddle assemblies 302, 322  
and 342, which are each coupled to one of piezoelectric  
generators 304, 324 and 344. Each of paddle  
assemblies 302, 322 and 342 is somewhat similar to  
paddle assembly 100 of FIG. 1, in that each paddle  
15 assembly shown in FIG. 3 also includes a substantially  
planar surface that is held in place such that it may  
move in response to molecular impacts. In this  
instance, paddle assemblies 302, 322 and 342 are  
attached at one end which is generally referred to  
20 by numeral 380 in FIG. 3.

[0052] The piezoelectric generators are each formed  
from a portion of piezoelectric material and a resistor  
assembly. Generator 324, for example, which  
is substantially similar to generators 304 and 344,  
25 is illustrated to show the division between  
piezoelectric material 326 and resistor assembly 328.  
However, the division between the piezoelectric portion  
and the resistor assembly may also be observed in  
FIG. 3 for generators 304 and 344.

30 [0053] Resistor assemblies 308, 328 and 348 are each  
connected to two wires that are made from different  
material. For example, each of wires 307, 327 and 347  
are made from one material, while wires 309, 329

and 349 are all made from a different material. The other end of all of the wires are connected to a series of heat sinks 360, which are themselves mechanically coupled to a substrate 370 (which may, for example, be  
5 a silicon substrate). It should be noted that paddle assemblies 302, 322 and 342 are only connected to substrate 370 at one end, generally referred to by reference number 380, so that, for example, the paddle assemblies may easily vibrate up and down.

10 [0054] System 300 operates in accordance with the present invention as follows. The entire system is immersed in a fluid (i.e., a liquid or a gas) that is the working substance. Statistical variations in the velocity of working substance molecules that  
15 strike paddle 302, for example, cause the free end of paddle 302 to vibrate up and down. The up and down motion of paddle 302 causes strain in piezoelectric material 306, which generates a voltage between lower conductive outer layer 385 and upper conductive  
20 layer 387 of material 306.

[0055] Outer conductive layers 385 and 387 of material 306 are in contact with resistor assembly 308, so that a current flows from material 306 through resistor 308 and back to material 306. The current  
25 through resistor 308 heats up the resistor, which is coupled to one side of the thermoelectric generator formed by wires 307 and 309 (which, as described above, are made from different materials). The other side of the thermoelectric generator (which may also be  
30 referred to as a thermocouple) is coupled to heat sinks 360, which are at a lower temperature. Persons skilled in the art will appreciate that other devices may be used, such as thermal to electric heat engines (such as, for example, a thermionic heat engine),

rather than thermoelectric generators described herein, without departing from the spirit of the present invention.

[0056]       The temperature differential causes the  
5 thermoelectric generator to produce a voltage, which, as described more fully below, may be combined with the voltages from other paddle assemblies to provide a system output voltage. These voltages, in accordance with the present invention, may be coupled together in  
10 series to produce an electrical output at a useable level from system 300. The process of summing voltages from each paddle assembly is more particularly illustrated with respect to FIGS. 5 and 6 below.

[0057]       Persons skilled in the art will appreciate  
15 that, while system 300 has been described as a system that converts kinetic energy of the impact mass (resulting from the Brownian motion of the impact mass immersed in a working substance) to AC electrical energy to thermal energy and to DC electrical energy,  
20 system 300 may, with minor changes, directly produce DC electric energy as a result of this kinetic energy.

[0058]       In particular, it should be noted that movement of paddle 302 upward and then downward to its resting location generates a voltage of one polarity.  
25 Movement downward and then upward back to the resting location generates a voltage in the opposite polarity. Thus, in accordance with the present invention, paddles 302 can be substantially limited to moving between a neutral point (i.e., the resting location)  
30 and a single limit point (versus normal vibration that goes from a first limit point, through the neutral point to a second limit point and back).



- [0059] Accordingly, if paddle 302 were limited to "upward" movement by placing an object at location 303 (i.e., toward the free end of paddle 302), the output voltage would be limited to one polarity (essentially, pulsating DC). In such a configuration, the outputs of the piezoelectric generators (such as generator 304) could be directly coupled together in series, which would eliminate the need of, for example, resistor assembly 308, wires 307 and 309 and heat sinks 360, while still providing useful levels of electrical power without the need for rectification circuitry.
- [0060] FIG. 4 shows another embodiment of a portion of a nanometer scale electromechanical system 400 constructed in accordance with the principles of the present invention. The portion of system 400 shown in FIG. 4 includes three paddle assemblies 402, 422 and 442, which are each coupled to one of piezoelectric generators 304, 324 and 344 (which were described above with respect to FIG. 3).
- [0061] As shown in FIG. 4, each of the paddle assemblies 402, 422 and 442 includes an impact mass 490 and a multitude of nanotubes 492 that are mounted on impact mass 490 such that they are substantially perpendicular to impact mass 490. Each of nanotubes 492 may, for example, be constructed of a material such as carbon, having a diameter of about approximately 2 nanometers and a height of about approximately 25-50 nanometers (persons skilled in the art will appreciate that the dimensions of nanotubes 492 may be varied without departing from the spirit of the present invention). Moreover, the stiffness and alignment of nanotubes 492 may be

controlled by the application of a static voltage, such as that shown in FIG. 7, and described below.

[0062] System 400 operates in very much the same way as previously described for system 300. Statistical  
5 variation in gas pressure about paddles 402, 422 and 442 cause the free end of paddle 402 to vibrate up and down, thereby causing strain in the piezoelectric material, which generates a voltage on the conductive outer layers of the piezoelectric  
10 material. In system 400, however, the up and down motion of the paddles in system 400 may be enhanced by nanotubes 492, which cause additional molecular impacts.

[0063] The outer conductive layers of the  
15 piezoelectric material are in contact with resistor assembly, so that a current flows, which heats up the resistor. The thermoelectric generator formed, for example, by wires 307 and 309 is between the heated resistor and the heat sinks 360, which are at a lower  
20 temperature. The temperature differential causes the thermoelectric generator to produce a voltage.

[0064] FIGS. 5 and 6 show two similar configurations of nanometer scale electromechanical systems 500 and 600, respectively, that are each constructed in  
25 accordance with the principles of the present invention. Systems 500 and 600 each include a multitude of paddle assemblies 302, coupled to generators 304 which are themselves, coupled to wires 307 and 309 that are connected to heat sinks 360.  
30 This may be more apparent by viewing the dashed box showing where the portion of system 300 of FIG. 3, for example, may be found. As shown in FIGS. 5 and 6, systems 500 and 600 each include ninety paddle

assemblies 302 and the associated components (i.e., generators, wires and heat sinks).

[0065] In practice, nanometer scale electromechanical systems constructed accordance  
5 with the present invention may include a billion or more paddle assemblies on a single substrate. The output voltage across each pair of wires extending from each thermoelectric generator on a single substrate are, in accordance with the present invention, coupled  
10 together in series to provide a single output signal for the system. That output signal may have a voltage that may be on the order of a volt, depending on the number of individual components used and the specific fabrication techniques used to manufacture those  
15 components. The primary difference between systems 500 and 600, is that system 500 includes a load resistor 502 while system 600 does not.

[0066] Persons skilled in the art will appreciate that, while load resistor 502 is shown as being mounted  
20 to substrate 370, it may be preferable to thermally isolate load resistor from the working fluid substrate 370 is immersed in so that heat dissipated by load resistor 502 does not affect the temperature of the working fluid.

25 [0067] FIG. 7 shows another embodiment of a nanometer scale electromechanical system 700 constructed in accordance with the principles of the present invention. System 700 includes an array of nanotubes 702 located between an upper plate 704 and  
30 lower plate 706 of capacitor 708, and a source of voltage 710, which is also coupled across the plates of capacitor 708. Each of nanotubes 702 may, for example, be constructed of a material such as carbon, having a

diameter of about approximately 2 nanometers and a height of about approximately 25-50 nanometers (persons skilled in the art will appreciate that the dimensions of nanotubes 702 may be varied without departing from the spirit of the present invention).

[0068] One end of each nanotube 702 is fixed to lower plate 706 of capacitor 708. The other end of each nanotube 702 is free to move. The entire assembly 700 is then typically immersed in a fluid (i.e., gas or liquid). Once a voltage V is applied from source 710 across the plates of capacitor 708, an electric field E is produced that creates a force that helps keep the length of nanotubes 702 oriented substantially perpendicular with the surface of capacitor plates 704 and 706. Statistical variations in the speed and direction of working fluid molecules which strike nanotubes 702 cause statistical variations in fluid pressure about nanotubes 702 which, in turn, cause nanotubes 702 to move erratically as illustrated in FIGS. 8 and 9.

[0069] As shown in FIG. 8, nanotubes 802 and 822 (which are simply any two adjacent nanotubes 702) are substantially perpendicular to lower capacitor plate 706 even though individual molecules 110 have recently impacted each nanotube. In this instance, there is no variation in the gas pressure on either side of the nanotubes, and the tubes remain erect. Persons skilled in the art will appreciate that, while the interaction of two nanotubes is shown, the molecular impact of thousands or millions of nanotubes would be occurring simultaneously.

[0070] FIG. 9, on the other hand, illustrates the effect of statistical variation in fluid pressure about

nanotubes 902 and 922 (which, like nanotubes 802 and 822, are simply two adjacent nanotubes 702) resulting from variations in the thermal movement of working fluid molecules, which cause the free ends of  
5 nanotubes 902 and 922 to collide at location 930. The kinetic energy of colliding nanotubes 902 and 922 is partially converted into thermal energy as a result of the friction from contact and as the tubes slide past each other. The thermal energy is conducted down the  
10 length of nanotubes 902 and 922 to thermally conductive plate 706.

[0071] In addition, as illustrated in FIGS. 8 and 9, each of nanotubes 702 (or nanotubes 802, 822, 902 and 922) has an electrostatic charge due to the  
15 electric field E between capacitor plates 704 and 706. The collision of nanotubes 902 and 922 further dissipates tube kinetic energy by accelerating electrical charges, which in turn produces electromagnetic waves, at the free end of the  
20 nanotubes. In this manner, a portion of the kinetic energy of the working fluid is transferred to lower capacitor plate 706, and to the surrounding space, as electromagnetic energy resulting in a net effect of cooling the working substance and heating lower  
25 capacitor plate 706. This temperature differential may then be used to directly heat or cool an area of space or to power a heat engine.

[0072] FIG. 10 shows another embodiment of a nanometer scale electromechanical assembly 1000  
30 constructed in accordance with the present invention. Assembly 1000 includes many nanotubes 1002, all connected to a base 1004. Unlike the previous embodiments, nanotubes 1002 are closed at their upper end such that gas molecules are captured within each

nanotube 1002. In addition, as shown in FIG. 10, at least one molecule in each nanotube 1002 is electrically charged (for example, individual nanotube 1012 includes at least one positively charged molecule, while individual nanotube 1022 includes at least one negatively charged molecule).

[0073] Assembly 1000 is configured such that the net charge of nanotubes 1002 in the assembly is zero, with half of the tubes including positive charges and the other half including negative charges. In this embodiment, as the charged molecules bounce against the nanotube walls and the other molecules within the nanotubes, an acceleration of charge results that generates electromagnetic waves which pass through the tube assembly to the surrounding space. As a result of the electromagnetic radiation, gas within nanotubes 1002 cools, which cools thermally conductive base 1004. In this instance, the reduced temperature of base 1004 may be utilized to cool a volume of fluid, or can be used as the "cold side" of a heat engine, as will be apparent to persons skilled in the art.

[0074] FIG. 11 shows a nanometer scale electromechanical assembly 1100 constructed in accordance with the principles of the present invention. Assembly 1100 includes a series of nanometer members 1102 that are connected between a pair of electrically and thermally conductive rails 1104 and 1106. In this embodiment, nanometer members 1102 are carbon nanotubes and each one of nanotubes 1102 is provided with some slack, which enables the nanotubes to vibrate in reaction to random pressure variations in the surrounding working substance. Rails 1104 and 1106 are mounted to and in thermal contact with thermally conductive base 1108.

[0075] It should be noted that various other nanometer members may be used in accordance with the present invention instead of the nanotubes described herein. For example, the principles of the present invention may be carried out using essentially any electrically conductive material that may be formed into very small fibers. This may include simple carbon fibers instead of nanotubes.

[0076] The nanometer members shown in FIGS. 11 and 12 (as well as those of FIGS. 13-16 discussed below) perform additional functions when compared to, for example, the previously described paddles. For example, the nanometer members of FIGS. 11-16 all function as the impact mass while contributing to the functions of the previously described restraining member and generator device. In addition, the nanometer members of FIGS. 11 and 12 also function as the resistive element (FIGS. 13-16 include resistive element 1304, as described more fully below).

[0077] Attached to thermally conductive base 1108, in accordance with the principles of the present invention, is a thermal insulation material 1110 that covers at least a majority of the otherwise exposed portions of conductive base 1108. The use of insulation 1110 aides in the prevention of thermal energy losses. Moreover, persons skilled in the art will appreciate that similar insulation may be utilized in the previously described embodiments to further increase the efficiency of those systems and assemblies.

[0078] An external magnetic field (shown as " $\vec{B}$ " in FIG. 11) penetrates assembly 1100 which is perpendicular to rails 1104 and 1106 and base 1108.

The operation of assembly 1100 is illustrated in FIG. 12, which shows a portion of rails 1104 and 1106, and includes two individual nanotubes 1202 and 1222 (which are simply two adjacent nanotubes 1102).

- 5 Nanotubes 1202 and 1222, which are immersed in a working substance, move in an irregular manner from the relaxed "rest" position (shown as straight dotted lines 1203 and 1223) due to random variations in the thermal motion of the molecules of the working  
10 substance. Motion of nanotubes 1202 and 1222 in the presence of the magnetic field  $\otimes \vec{B}$  induces an electric field  $\vec{E}$  along the length of nanotubes 1202 and 1222 (as shown in FIG. 12).

- [0079] Field  $\vec{E}$  induces current " $i$ " to flow that  
15 flows from one nanotube, down one rail, across the other nanotube, and up the other rail (which, while illustrated as a clockwise current, may be counterclockwise at some other point in time when the direction of the motion of the nanotubes changes,  
20 thereby producing AC current). The current flow through the nanotubes and rails causes resistive heating and causes heat to travel along the nanotubes and rails to conductive base 1108. Fluid (either gas or liquid) surrounding the nanotubes cools while base  
25 1108 heats up, thereby establishing a temperature differential that may be used in a variety of ways (such as the heat pump, or heat engine previously described).

- [0080] FIGS. 13-16 show a further illustration  
30 of the use of insulation in accordance with the principles of the present invention in assembly 1300. Assembly 1300 is similar to assembly 1100 of FIG. 11 in many aspects. Assembly 1300 also includes



nanotubes 1302 that are immersed in a working substance. Moreover, as described above with respect to nanotubes 1102, nanotubes 1302 are installed with slack such that they can move in an irregular manner due to random fluctuations in the thermal motion of the molecules of the working substance.

[0081] Assembly 1300 also relies on an external magnetic field  $\vec{B}$ . As previously described, motion of nanotubes 1302 through the magnetic field  $\vec{B}$  induces an AC current to flow, which in this case, is directed through a resistor 1304 located directly below each of nanotubes 1302. The value of resistor 1304 may be chosen to be about twice the resistance of the nanotube, in which case the majority of power generated is dissipated as heat through the resistor.

[0082] Assembly 1300 is configured such that the resistors 1304 are located below insulating layer 1310 and above thermally conductive sheet 1312. This results in directing most of the generated power and heat downward into assembly 1300, rather than up into the working fluid. Moreover, rather than using rails, assembly 1300 utilizes posts 1306, so that only a limited amount of surface area that is at an elevated temperature is exposed to the working fluid.

Resistors 1304, posts 1306 and the resistor leads are electrically insulated from thermally conductive sheet 1312 by a thin layer of electrical insulation 1314 that is deposited on top of conductive layer 1312.

[0083] Heat from resistor 1304 raises the temperature of thermally conductive sheet 1312. The bottom of conductive sheet 1312 is in thermal contact with a "HOT" portion 1330 of a thermoelectric

- generator 1334 (sheet 1312 is electrically insulated from hot portion 1330 via electrically insulating sheet 1316). A second thermally conductive sheet 1322 is in thermal contact with a "COLD" portion 1332 of a thermoelectric generator 1334 (while the two are electrically insulated by thin layer 1318). In this manner, generated heat is directed from resistors 1304 downward through assembly 1300 and out the bottom of lower layer 1322.
- 10 [0084] Temperature differentials between the HOT and COLD portions (1330 and 1332, respectively) of thermoelectric generator 1334 create a DC voltage across each junction. By interconnecting a multitude of these junctions together in series, assembly 1300
- 15 may be used to provide a useable voltage which may be about at least 1 volt, as was previously described for the other embodiments. When assembly 1300 is used to drive a load, such that the load is connected in series to thermoelectric generator 1334, and the working fluid
- 20 is being cooled or maintained within a predetermined temperature range, improved efficiency of the system will be obtained by keeping the load away from the working fluid so that dissipated power in the load does not affect the temperature of the working fluid.
- 25 [0085] Moreover, as can be viewed most clearly in FIG. 15, additional layers of thermal insulation are used to separate the HOT portions of assembly 1300 from the COLD portions of assembly 1300. In particular, assembly 1300 also includes insulating layer 1342
- 30 sandwiched between conductive sheet 1312 (actually, as shown, layer 1342 is below electrical insulating layer 1316) and COLD portion 1332. Insulating layer 1352, on the other hand, is located between a second conductive sheet 1322 and HOT portion 1330

(actually, as shown, layer 1352 is underneath electrically insulating layer 1318). These insulating layers increase the temperature difference between HOT and COLD portions of thermoelectric generator, thus  
5 increasing the electrical output of thermoelectric generator 1334.

[0086] Operation of assembly 1300 is similar to assembly 1100, and is illustrated with respect to FIG. 16. Movement of nanotubes 1302 in the external  
10 magnetic field  $\otimes \vec{B}$  induces a current "i" to flow as shown in FIG. 16. In this case, though, the current from each individual nanotube 1302 remains in a self-contained circuit, along with the corresponding resistor 1304. For example, the current induced in  
15 individual nanotube 1342 remains in an "isolated" circuit with individual resistor 1344, rather than interacting with an adjacent nanotube, as was described with respect to assembly 1100. Once again, persons skilled in the art will appreciate that, while the  
20 movement of two nanotubes is shown, the movement of millions or billions of nanotubes would be occurring simultaneously.

[0087] Persons skilled in the art should appreciate that, while it may appear that an individual  
25 thermoelectric generator portion is available for each individual nanotube 1302, it will likely be impractical and/or prohibitively expensive to implement such a configuration. Thus, it may be more likely that, in accordance with the present invention, several, if not  
30 millions, of nanotubes 1302 will be thermally coupled to each individual portion of thermoelectric generator 1334.

- [0088] FIG. 17 shows a propulsion system 1700 constructed in accordance with the present invention in which an object immersed in a working substance is moved in a controllable direction as a result of
- 5 variations in molecular impacts of working substance molecules into the object. System 1700 includes sphere 1702 and a series of electromagnets 1704, 1706, 1708, 1710, 1712 and 1714 (1712 and 1714 are shown as a single pair of dotted lines) arranged axially about
- 10 electronics core 1716 (axially simply refers to the fact that there is one electromagnet located parallel to each of the six sides of electronics core 1716, and that each electromagnet may have its center aligned with an imaginary axis extending perpendicular to the
- 15 core surface). These electromagnets, along with a control system form a drive system that, as set forth in more detail below, helps to propel sphere 1702.
- [0089] Sphere 1702 may be any three-dimensional object. Although a sphere is shown, other shapes such
- 20 as a cube, cylinder, etc., may be used. The surface of sphere 1702 is covered with nanometer scale assemblies, such as a series of nanotubes, that are mounted to the surface with some slack, as described above with respect to FIGS. 11-16.
- 25 [0090] Electromagnets 1704, 1706, 1708, 1710, 1712 and 1714 may be powered from, for example, a battery or some other source. In any case, external power is provided to electronics core 1716 that is then provided to the appropriate electromagnets, as described below.
- 30 [0091] Assuming sphere 1702 is located in a fluid maintained at non-zero temperature, when one electromagnet is energized, such as electromagnet 1704, the resultant magnetic field 1718, along with the nanotube assembly, lowers the fluid pressure

immediately above the surface. The reduced pressure causes sphere 1702 to move in direction 1720 (if the propulsion force is strong enough). If, for example, electromagnet 1710 is also energized, thereby  
5 establishing magnetic field 1722, a force 1724 also affects sphere 1702. In this instance, sphere 1702 would be propelled along a vector 45 degrees away from magnetic axes 1718 and 1722 (as shown by arrow 1726). By varying the current supplied to each of the  
10 electromagnets, the movement of sphere 1702 through a fluid can be controlled.

[0092] From the foregoing description, persons skilled in the art will recognize that this invention provides nanometer scale electromechanical assemblies  
15 and systems that may be used to convert one form of energy to another. These assemblies and systems may be used to provide, for example, heat engines, heat pumps or propulsion devices. In addition, persons skilled in the art will appreciate that the various configurations  
20 described herein may be combined without departing from the present invention. For example, the nanotubes shown in FIG. 4 may be mounted directly to piezoelectric generators of FIG. 4, instead of the configuration shown. It will also be recognized that  
25 the invention may take many forms other than those disclosed in this specification. Accordingly, it is emphasized that the invention is not limited to the disclosed methods, systems and apparatuses, but is intended to include variations to and modifications  
30 thereof which are within the spirit of the following claims.